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EARLY ORDOVICIAN (ARENIG) GRAPTOLITES FROM THE UPPER ST. GEORGE GROUP, PORT AU PORT PENINSULA: PRESERVATION, CORRELATION, AND PALEO-ENVIRONMENTAL AND STRATIGRAPHIC IMPLICATIONS

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ABSTRACT

Locally abundant, exquisitely preserved graptolites belonging to Didymograptellus bifidus *are preserved in shallow-water carbonate rocks of the upper part of the Lower Ordovician St. George Group in newly exposed roadside outcrops at the west end of Port au Port Peninsula, western Newfoundland. The fauna, which accompanies a diverse shelly assemblage, occurs within 20 m of the top of the Costa Bay Member, Catoche Formation. The graptolites preserved in both limestones and dolostones add to other graptolitic intervals at about the same stratigraphic level elsewhere in Newfoundland. This may support a shelf-wide marine incursion of Iapetan ocean waters onto the shelf at this time. However, the graptolites appear to mark the base of a transition from open-shelf sedimentation via a high energy, carbonate sand barrier, to restricted peritidal sedimentation across the Catoche and Aguathuna formations boundary and were probably concentrated at this interval by hydrodynamic and geochemical conditions seaward of the barrier. In addition, the open shelf to peritidal transition is younger in the south (*D. bifidus *zone) than in the north (*P. fruticosus *zone).*

INTRODUCTION

The subtidal to peritidal carbonate rocks of the St. George Group (Knight and James, 1987) have been divided into the Watts Bight, Boat Harbour, Catoche and Aguathuna formations, which based on trilobite and conodont evidence, appear to range in age from earliest Ordovician (Canadian (Gasconadian/Tremadoc)) to probably Early mid Ordovician (early Whiterock/mid-Arenig) (e.g., Stouge, 1982; Boyce, 1989; Williams *et al.,* 1987; Stait and Barnes, 1991; Ji and Barnes, 1994; Boyce and Stouge, 1997; Boyce *et al., this volume*). A number of roadcuts along Route 463 between Cape St. George and Mainland[3], west end of the Port au Port Peninsula, western Newfoundland expose a broken section through carbonate rocks of the upper part of the St. George Group (Figure 1). The roadcut sections include strata from the Costa Bay Member, Catoche Formation and the overlying Aguathuna Formation (*see* Boyce *et al., this volume*). Graptolites are preserved in the upper part of the Costa Bay Member at the same stratigraphic interval in two sections logged (Figure 2) but the best material occurs in the section on the east side of the road.

Graptolites occur through a 2.5 m interval within 20 m of the top of the Costa Bay Member. The graptolites, which are preserved in both limestone and dolostone and are the focus of this short paper, were first noticed by Dr. E.A. Measures in 1998. Additional horizons were later discovered and collected by W.D. Boyce and I. Knight in 1998 and 1999 during detailed section logging performed by I. Knight. Description and final identification of the collected fauna is the work of the principle author (S.H. Williams).

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[3] The highway was constructed across the Peninsula in 1994.

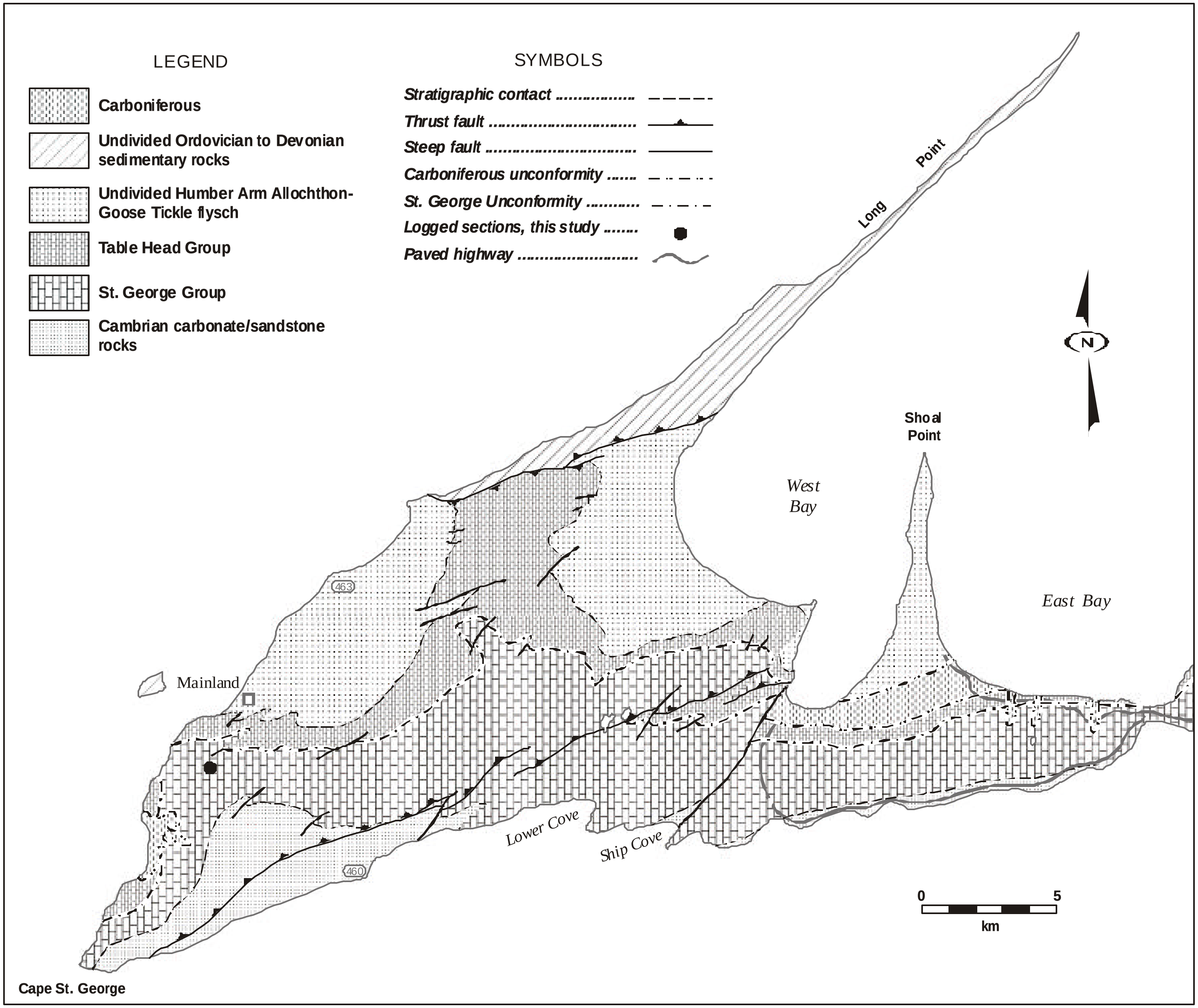

Figure 1. *Simplified geological map of the Port au Port Peninsula showing the location of the section at the west end of the Peninsula that hosts the graptolites described herein. Map based on Stockmal and Waldron (1993).*

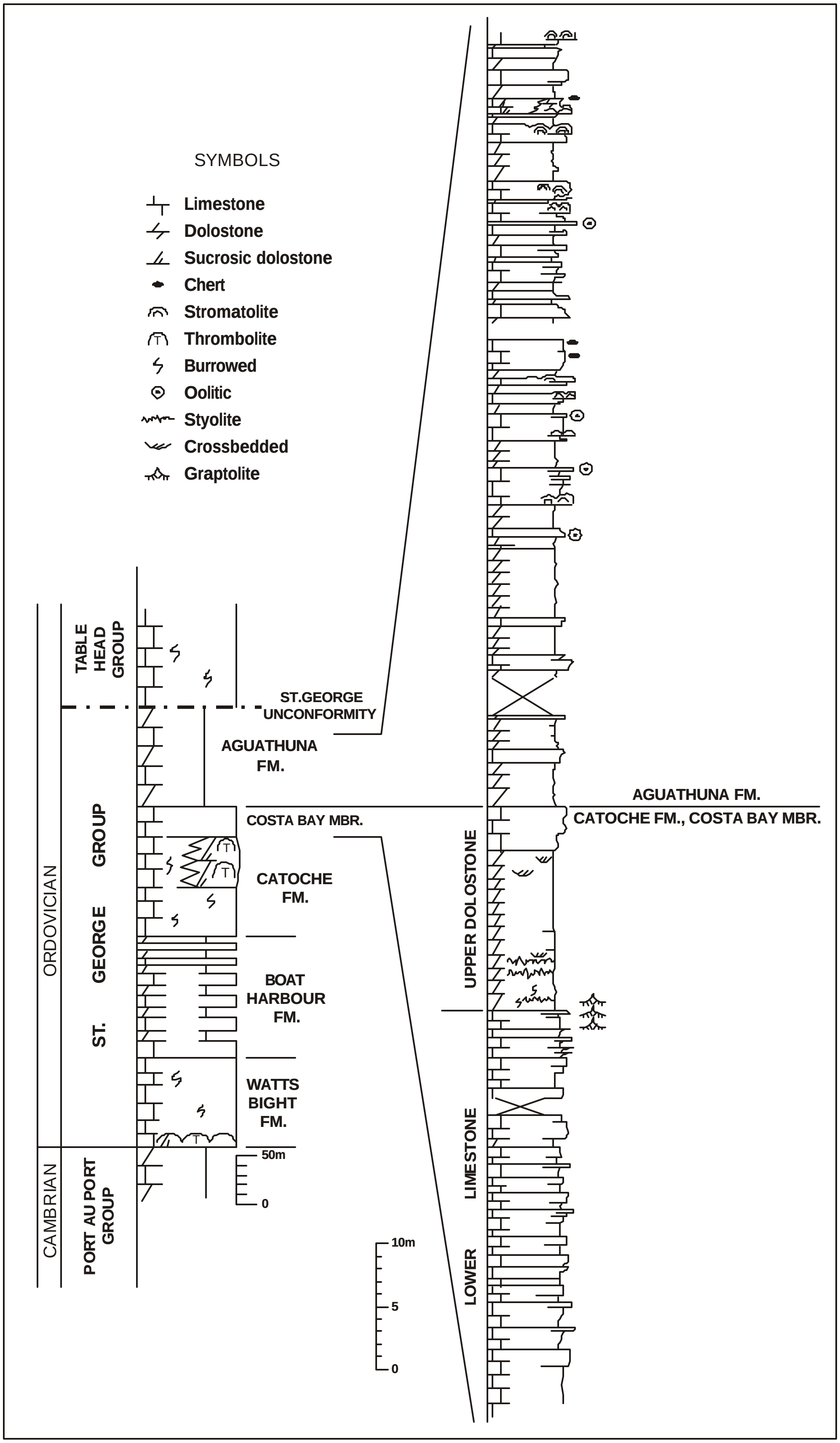

Figure 2. *Integrated graphic log of the sections through the Costa Bay Member and the Aguathuna Formation at the Route 460 road sections, western Port au Port Peninsula (*see *Boyce* et al., this volume *for detailed log). The lithostratigraphic position of the section is shown within the overall stratigraphy of the Ordovician shelf sequence in western Newfoundland (based on Knight and James, 1987; Knight and Cawood, 1992; Knight, unpublished data).*

LITHOSTRATIGRAPHY AND ENVIRONMENT

The Costa Bay Member is the uppermost division of the Catoche Formation overlying a middle mound member and a lower bioturbated limestone member in the Port au Port area. In the formation type section area at Port au Choix, Great Northern Peninsula, the member is entirely dolomitized and hence unfossiliferous and rests upon a lower bioturbated limestone with several stratigraphically spaced moundstone beds. The member is generally unfossiliferous elsewhere in western Newfoundland even though it remains limestone.

The Costa Bay Member at its type section at the Aguathuna quarry, eastern Port au Port Peninsula is a clean, white peloidal grainstone 35 m thick (Knight, 1996). In the present study area, the member consists of a lower limestone, which is very fossiliferous, and an upper crystalline dolostone, that together attain a thickness of approximately 50 m. The lower limestone comprises 33 m of repetitive coarsening-upward cycles, 0.35 to 7.5 m thick, of stylonodular, fossiliferous, dolomitic mudstone–wackestone, variably bioturbated and dolomitic, fossiliferous, peloidal wackestone–packstone–grainstone and oncolitic, skeletal, intraclastic-peloidal floatstone–rudstone–grainstone (Figure 2; *see* Boyce *et al., this volume* for detailed description).

Graptolites occur in the uppermost 1.6 m of the lower limestone where they are distributed throughout the different lithofacies of a coarsening-upward cycle but are most numerous and complete in burrowed, peloidal wackestone and packstone just below a peloidal and intraclastic packstone–grainstone in the upper 20 cm of the cycle. The graptolitic cycle rests upon a 2.2 m interval of four decametre-scale cycles that are dominated by rubbly weathering, stylonodular, dolomitic lime mudstone–wackestone having a thin centimetre-thick cap of intraclastic rudstone. The bed immediately below the graptolite cycle is exceptionally rich in shelly fossils (*see* Boyce *et al., this volume*).

The upper dolostone of the Costa Bay Member, which is approximately 17 m thick, immediately overlies the graptolitic bed. It comprises 3 m of finely to finely crystalline, dark grey to grey, burrow-mottled dolostones overlain by 11 m of crossbedded dolarenite capped by 3.7 m of limestone below the first dololaminite bed of the Aguathuna Formation. A graptolite horizon occurs 47 cm above the base of the burrowed dolostone.

A low to moderate energy, open-shelf setting seaward of a high-energy carbonate sand-barrier complex is envisaged for the lower limestone of the Costa Bay Member at the western extremity of the Port au Port Peninsula (*see* Boyce *et al., this volume*). Metre-scale cyclicity throughout the lower limestone suggests essentially stable facies belts influenced by 5th order sea-level fluctuations. The dolostones at the top of the member, however, preserve most of a decimetre-thick, shallowing-upward sequence beginning with low-energy, deeper water, fossil-rich carbonates (partly dolomitized) and culminating in high-energy, crossbedded carbonate sands (now dolomitized) of a barrier complex. As such, the sequence marks the transition from the open-shelf setting of the lower Costa Bay Member to the more restricted peritidal flat complex of the overlying Aguathuna Formation. This significantly thicker shoaling-upward sequence, which hosts both plentiful graptolites and a diverse shelly fauna in the low-energy carbonates of the lower part of the sequence, may indicate an important marine flooding event onto the shelf at this time.

The abundance of graptolites at the top of the Costa Bay Member may also reflect the nearshore setting of this transition. The graptolites would not only be concentrated by local hydrodynamic conditions along the foreshore of the barrier complex but this paleogeographic location likely heightened the potential for mortality by both turbidity and turbulence. In addition, geochemical environmental stress must have occurred at times when hypersaline brines were flushed from the broad back-barrier lagoons and tidal flats inboard of the barrier complex out into the open marine fore-barrier zone during severe storms. This must have occurred through tidal inlets or wherever the barrier was destructively breached.

GRAPTOLITE BIOSTRATIGRAPHY

Graptolites, despite being rare in the autochthonous, shallow-marine carbonates of the Lower to Middle Ordovician St. George Group of western Newfoundland, have proved important in confirming biostratigraphic ages and permitting correlation into the partly coeval deep-water allochthonous carbonates of the Cow Head Group (Williams *et al.*, 1987). The present study documents additional graptolitic horizons within the St. George Group, and both provide further biostratigraphic information and shed light on aspects of graptolite paleoecology.

KNOWN GRAPTOLITES FROM THE ST. GEORGE GROUP

Graptolites have been recovered previously from two formations in the St. George Group, the Catoche Formation and the Aguathuna Formation. Those from the Catoche Formation were recovered from 8 horizons distributed throughout the lower limestone, including the Laignet Point Member (Knight, 1977), at Port au Choix (Kindle, 1945; Cumming, 1967; Boyce, 1985; Williams *et al.*, 1987). The fauna includes *Clonograptus flexilis* (J. Hall), probable *Pseudophyllograptus pristinus* Williams and Stevens (recorded by Williams *et al.* (1987) as "*Pseudophyllograptus* sp.") and benthic dendroid graptolites. Williams *et al.* (1987) concluded that this assemblage indicated a correlation with Bed 9 of the Cow Head Group, equivalent to the *Tetragraptus approximatus* and/or the *Tetragraptus akzharensis* zones of Williams and Stevens (1987, 1988).

Graptolites are known from only one locality in the Aguathuna Formation in the northern part of the Table Point (Provincial) Ecological Reserve on the Great Northern Peninsula. They are hosted by a dark, fine-grained dolostone unit that occurs near the base of the formation (Unit 1, Knight and James, 1988). Although first recorded long ago (Schuchert and Dunbar, 1934; Ruedemann, 1947), the graptolites were thoroughly recollected and restudied by Williams *et al.* (1987) who showed them to represent a monospecific fauna of *Didymograptus (Expansograptus) nitidus* (J. Hall). By comparison with the study of Williams and Stevens (1987, 1988), Williams *et al.* (1987) concluded that this part of the Aguathuna Formation correlated with the lower or middle part of Bed 11 of the Cow Head Group (*Pendeograptus fruticosus* or *Didymograptus bifidus* zones)[4].

NEWLY RECOVERED GRAPTOLITES FROM THE COSTA BAY MEMBER, CATOCHE FORMATION, PORT AU PORT PENINSULA

The graptolites recovered from three closely spaced localities in a 3.5 m section 20 m from the top of the Costa Bay Member, Catoche Formation all yielded a monospecific fauna of *Didymograptellus bifidus* (J. Hall), a species restricted to the middle part of Bed 11 (*D. bifidus* Zone) of the Cow Head Group (Williams and Stevens, 1988). This appears to agree well with the conclusions of Williams *et al.* (1987) based on the recovery of *D. (E.) nitidus* from the basal bed of the Aguathuna Formation at Table Point, but provides tighter biostratigraphic control to bracket the timing of the transition from subtidal shelf deposition of the Catoche Formation to widespread peritidal sedimentation of the Aguathuna Formation throughout western Newfoundland.

The graptolites preserved in limestones of the topmost metre-scale cycle of the lower limestone are best preserved within a moderately bioturbated, medium-grey limestone bed some 7 cm thick, where they are found both concentrated along two laminae and scattered throughout the remainder of the bed. Although some are broken by and bent around the 0.5 to 1.0 cm burrows, most others were clearly fragmented during deposition, but a surprising number of both large and immature rhabdosomes are preserved intact. They all retain organic material and many are preserved in full or partial relief, particularly at the levels away from the laminae with concentrated remains. The preservation is so good it is possible that they could be chemically isolated from the matrix.

Graptolites, recovered from finely crystalline dolostone at the base of the upper dolostone unit, are found intact along several discrete laminae but lack any organic periderm. They are, however, preserved in full relief and are visible due to the white dolomitic infill of the rhabdosome, which must have occurred prior to compaction or oxidation of the organic skeleton, thus supporting an early shallow burial origin for the dolomite.

The presence of *D. bifidus* in these rocks is perhaps unexpected based on the accepted understanding of graptolite paleoecology. Williams *et al*. (1987) remarked that whereas a robust rhabdosome such as *Pseudophyllograptus* and diplograptids might be expected to have inhabited turbulent, shallow water, some more slender and branching forms (such as *Clonograptus flexilis* and *Didymograptus (Expansograptus) nitidus*) surprisingly must also have been able to tolerate such conditions. To this list can now also be added the pendent didymograptids. Perhaps a clue to a lifestyle in turbulent conditions is the presence of extreme secondary (both fusellar and cortical) thickening of the proximal region of many rhabdosomes during life (compare Figures 3a, b and d with Figures 3c and e).

D. bifidus is a characteristic "Pacific province" species; the previously so-called "*D. bifidus*" of the UK Llanvirn are now known to belong to *Didymograptus artus* (Elles and Wood), an unrelated group of graptolites (*see* Maletz, 1994). Pacific province graptolites are considered to have inhabited warm, low-latitude marine environments (Cooper *et al*., 1991). The presence of *D. bifidus* (including a complete range of growth stages, which indicates a lack of significant post-mortem transport) confirms that this species inhabited both open-ocean and nearshore environments, and suggests

[4] It should be noted that Maletz (1994) included *D.(E.) nitidus* in the genus *Didymograptellus* (whose type species is *D. bifidus*). We agree that the proximal development is similar, and that the two are probably closely related; until further discussion addresses other related forms, including *D.(E.) pennatulus* (J. Hall) and *D.(E.) extensus* (J. Hall) we consider, however, that these extensiform didymograptids are best retained in the subgenus *Didymograptus (Expansograptus)*.

a habitat in the upper part of the water column as proposed by Cooper *et al*. (1991). Interestingly, those authors also comment that robust forms of *D. bifidus*, such as described here, are commonly found in their "inshore biotope".

In terms of depositional environment, Williams *et al*. (1987) considered that the occurrence of *D. (E.) nitidus* within atypical, dark dololaminites in the lower Aguathuna Formation suggests that they were washed into sediments being deposited in a (?supratidal) anoxic ponded setting during storm activity. The examples of *D. bifidus*, in contrast, occur in limestones hosting a more normal marine shelly fauna; although particularly concentrated along two laminae (which could represent either a mass kill or a storm event, see earlier environmental discussion) they are also scattered throughout several decimetres of limestone. This supports the interpretation that these Costa Bay sediments on the Port au Port Peninsula were deposited under fully marine, subtidal conditions (see earlier discussion and Boyce *et al., this volume*).

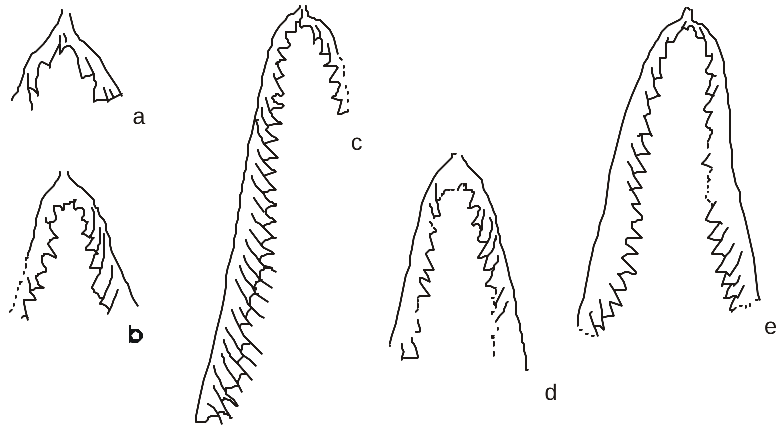

Figure 3a-e. *Didymograptellus bifidus (J. Hall), Costa Bay Member, Catoche Formation, Route 463, Port au Port Peninsula. a, x10, b-e, x5.*

Correlation of the Costa Bay graptolites at Port au Port Peninsula and the Aguathuna graptolites at Table Point within the same graptolite zone is possible since the ranges of the two graptolites overlap within the lower part of the *D. bifidus* zone. Based on the abundance of *D. bifidus* in the upper Costa Bay of the study area, but absence in the graptolitic Aguathuna Formation peritidal dolostones at Table Point, it is however, also a possibility that the lower Aguathuna Formation at Table Point was deposited during the previous *P. fruticosus* zone. In either case, this suggests that the development of restricted peritidal flat deposition occurred earlier in the north of western Newfoundland than in the south. Diagenetic dolostones that replace the top of the Catoche Formation at Port au Choix, Daniel's Harbour and Table Point are best correlated with the Costa Bay Member (*see* Knight, 1991 for brief discussion of vestiges of limestone in the Port au Choix dolostones that support this correlation) and would support the interpretation of diachronous-facies progradation from north to south. Alternatively, this difference in the timing of the transition from open to restricted marine platform between the two areas may reflect a marked disconnection of the distantly separated parts of the same regional platform and perhaps supports the importance of tectonism on the late stages of development of the Lower Ordovician platform (Knight and James, 1987; James *et al.,* 1989; Knight *et al.,* 1991).

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